

TITAN BALLOON BUOYANCY CONTROL ANALYSIS AND DEMONSTRATION

Interim Report

JPL Task 969

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A. OBJECTIVES

Titan, the largest moon of Saturn, is the only moon in our solar system with a significant atmosphere, and it happens to be ideally suited for balloon exploration. The nitrogen atmosphere has a pressure a bit higher than Earth's, and it is much colder at -180°C (Reference 1). This makes the density of the atmosphere four times as much as that of Earth, and thus helium balloons can carry four times as much payload. Titan is believed to have large solid land masses and cold, liquid hydrocarbon oceans. The goal of this program is to design, fabricate, and test a buoyancy-controlled balloon system for Titan that will allow complete atmospheric mobility below the methane ice cloud level (10 km altitude) and that can travel about the solid surfaces and liquid seas.

B. PROGRESS AND RESULTS

A number of balloon buoyancy and mobility systems have been considered, and the design with the most flexibility to accomplish all mobility-related science objectives has been determined to be a blimp modified with a large floatation wheel (Figure 1) that can land and operate on cryogenic solid surfaces or liquid seas (Reference 2).

One possible mission scenario is shown in Figure 2. After entry into Titan's atmosphere, a parachute would pull out a deflated blimp. While falling, the blimp would be filled with helium or hydrogen, and would gently descend to the surface due to a slightly positive weight. The Aeroover could then reascend using propeller power or by heating the blimp cavity with waste heat from a radioisotope thermal generator (RTG). The blimp could make repeated descents to the surface through direct commands from Earth or by autonomously seeking certain targets, such as biosignatures or heat sources. Although the surface winds are anticipated to be only about 0.5 m/sec (1.1 mph), at 10-km altitude the winds are strong enough to allow complete circumnavigation of the moon every one-to-two weeks. The Aeroover would essentially be "orbiting" Titan well below the upper, obscuring clouds and could, for the first time, allow detailed imaging of the moon, which appears only as an orange disk from space.

Initial testing of Aeroover concepts has begun with materials research and scale-model Aeroover mobility tests. The first Aeroover model tested was a commercially-available one-meter blimp that was modified to allow surface mobility (floatation/landing wheel added), with heat-activated altitude control (black patch added to absorb external radiant heat). The model exhibited excellent control both in the air and on solid surfaces. Altitude variations were fully controllable by engine fan thrusts, by radiant heat input (ascent), and convective cooling (descent).

A larger, six-meter commercially-available blimp has since been purchased and has been modified for testing as a Titan Aeroover (Figure 3). A landing floatation wheel has been added that will allow the blimp to land on solid land or lakes. The engines are rotatable to allow powered ascent. A series of internal, lightweight heating coils has been added, representing waste heat additions inside the blimp, and a thermal model of the system has been created. The measured buoyancy change has closely matched those analytically predicted (Figure 4). All future outdoor mobility test results will be compared with theory to ascertain accurate mobility and thermal models. A number of power vs. velocity measurements have already been made, as well as power vs. thrust measurements. These values have been compared with various numerical models and are discussed in the next section.

Another area of Aeroover research that was explored is that of the Aeroover envelope material. Although there are many polymer materials that can function well at cryogenic temperatures (Mylar, Kapton, Kevlar, PBO, etc.), it was previously unknown how to make a non-porous, strong, envelope whose gores could be sealed to survive Titan's 80-93 K temperatures. A breakthrough last year by Taconic Corporation, however, has demonstrated that a tough PBO fabric weave can be coated with Teflon and aluminized to create a lightweight, non-porous tough envelope, whose gores can be sealed with a Teflon precursor. The primary thrust for the near-term future work will be with autonomous mobility and demonstration of heat-activated buoyancy control.

C. SIGNIFICANCE OF RESULTS

There are several primary areas of significance for the results thus far. The first is that a combined aerobot/rover, or Aeroover, appears to be the best means to explore the atmosphere, solid surfaces, and liquid oceans of Saturn's moon, Titan. The second is that power measurements made on a 6-m blimp have confirmed a novel, empirical correlation (Reference 3) made by this task's science advisor, Professor Ralph Lorenz. Based on these calculations, we now know that approximately 90 watts of power (out of 110 watts available) are required to propel our 12.5 meter long, 200 kg Titan Aeroover at a speed of 1.0 m/sec, which is adequately above the 0.5 m/sec anticipated surface wind speeds at Titan. We have also calculated that this speed can be increased for the same power if the propellers are more efficiently designed. A third significant result is that a breakthrough materials advance has been made with the creation of a rugged, lightweight fabric material (Teflon-coated PBO) that can survive the cryogenic temperatures on the Titan surface. The fourth, and most recent, significant result is that our thermal models are accurately predicting buoyancy change as a function of waste heat input to the blimp (Figure 4). Due to Titan's low gravity, low temperature, and dense atmosphere, the lift created by adding 200 watts of heat inside the 12.5-m blimp is about 0.6 kg while the blimp is

floating in a stationary position above Titan. This should allow vibration-free science and imaging while traveling with the relatively high winds at 10 km altitude above the Titan surface.

D. FINANCIAL STATUS

The total funding for this task was \$100,000, all of which has been expended.

E. PERSONNEL

Other personnel contracted for this study include Tim Lachenmeier, President of Global Solutions for Science and Learning, as well as Professor James DeLaurier of the University of Toronto's Institute for Aerospace Studies.

F. PUBLICATIONS

- [1] Jack A. Jones, "Titan Amphibious Aerover," AIAA Space 2000 Conference, Long Beach, CA. September 19-21, 2000.
- [2] Jack A. Jones, "Inflatable Robotics for Planetary Applications," 6th International Symposium on Artificial Intelligence, Robotics, and Automation in Space", i SAIRAS, Montreal, Canada, June 19-21, 2001.
- [3] Jack A. Jones and Ralph Lorenz, "Titan Aerover All-Terrain Vehicle," Space Technology and Applications International Forum (STAIF-2002), Albuquerque, NM, February, 2002.
- [4] Jeffery L. Hall et al, "Titan Airship Explorer," IEEE Aerospace 2002 Conference, Big Sky Montana, March 2002.
- [5] Ralph D. Lorenz, "Flight Power Scaling of Airplanes, Airships, and Helicopters Applications to Planetary Exploration," *Journal of Aircraft*, Vol. 38, No. 2, March-April 2001.
- [6] Jack A. Jones, "Aerover Development at JPL/NASA," *SPIE Unmanned Ground Vehicle Technology Video Session*, Orlando, FL, 2002, JPL Video #2002_01_02.
- [7] JPL Titan Aerover URL (updated July 2001):
http://www.jpl.nasa.gov/adv_tech/balloons/outer.htm

G. REFERENCES

- [1] Ralph Lorenz, "2000 Post-Cassini Exploration of Titan: Science Rationale and Mission Concepts," *Journal of the British Interplanetary Society*, Vol. 53, pp. 218-234, 2000.
- [2] Jack A. Jones and Ralph D. Lorenz, "Titan Aerover All-Terrain Vehicle," Space Technology and Applications International Forum (STAIF-2002), Albuquerque, NM, February, 2002.
- [3] Ralph D. Lorenz, "Flight Power Scaling of Airplanes, Airships, and Helicopters: Application to Planetary Exploration," *Journal of Aircraft*, Vol. 38, No. 2, March-April 2001.

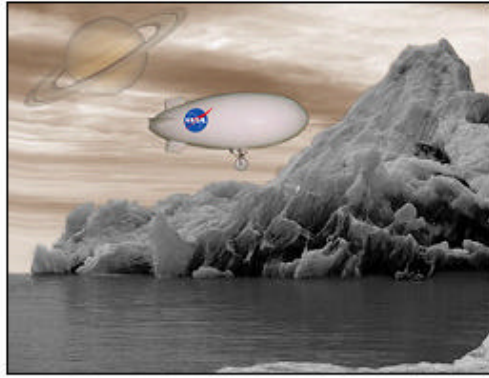


Figure 1. Titan Aerober

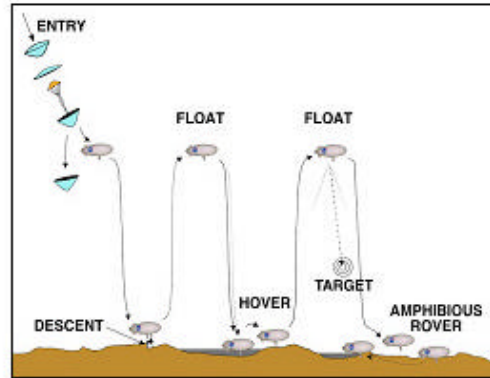


Figure 2. Mission Sequence



Figure 3. Titan Aerober Tests

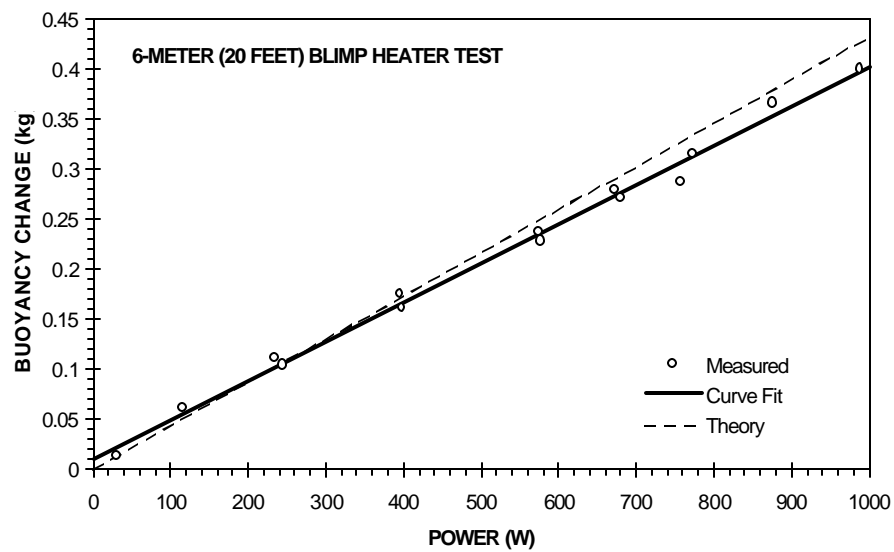


Figure 4. Buoyancy Change vs Blimp Heat Input